Influence of Curvature on Cone Formation in Electrified Liquids

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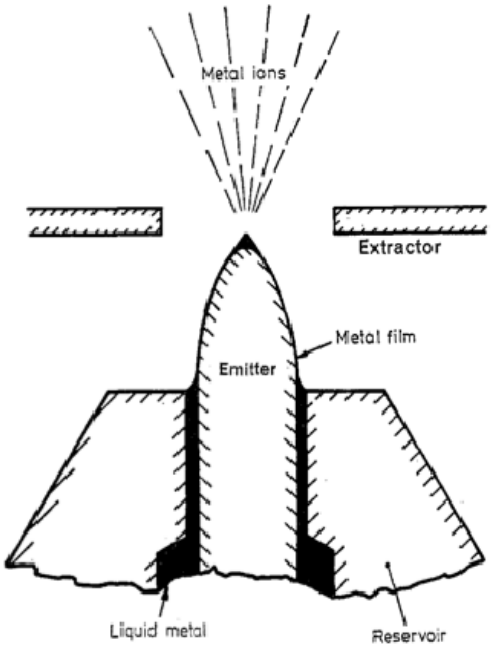
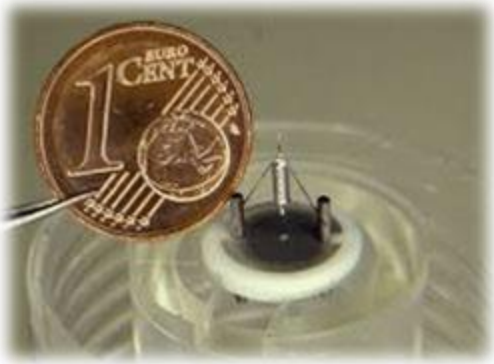
Link to Introduction Video

Caltech

Phenomenon: dynamic cones

- The surface of a liquid metal film forms a cone above a critical electric field strength
- The field at the cusp causes emission of metal ions as a beam
- I studied the dynamic formation of the cone
- Video: Electrospray

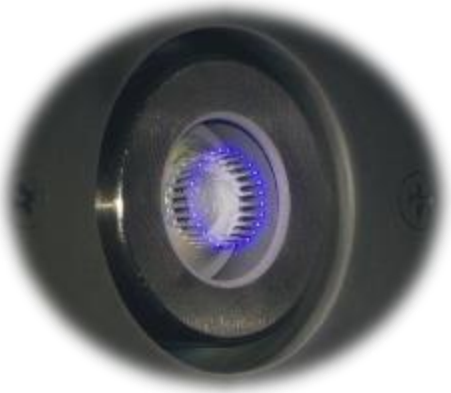




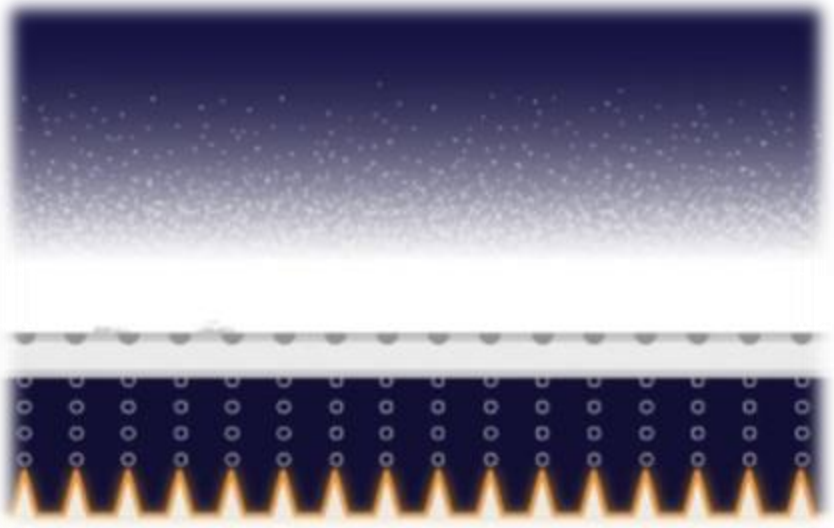
Liquid Metal Ion Source

Application: Focused ion beams

- Metal-ion beam uses:
  - Imaging in biological and materials sciences
  - Chip nanofabrication
- Miniaturized LMIS are efficient spacecraft propulsion devices
- Miniaturization makes instabilities in the cusp we want to understand/mitigate



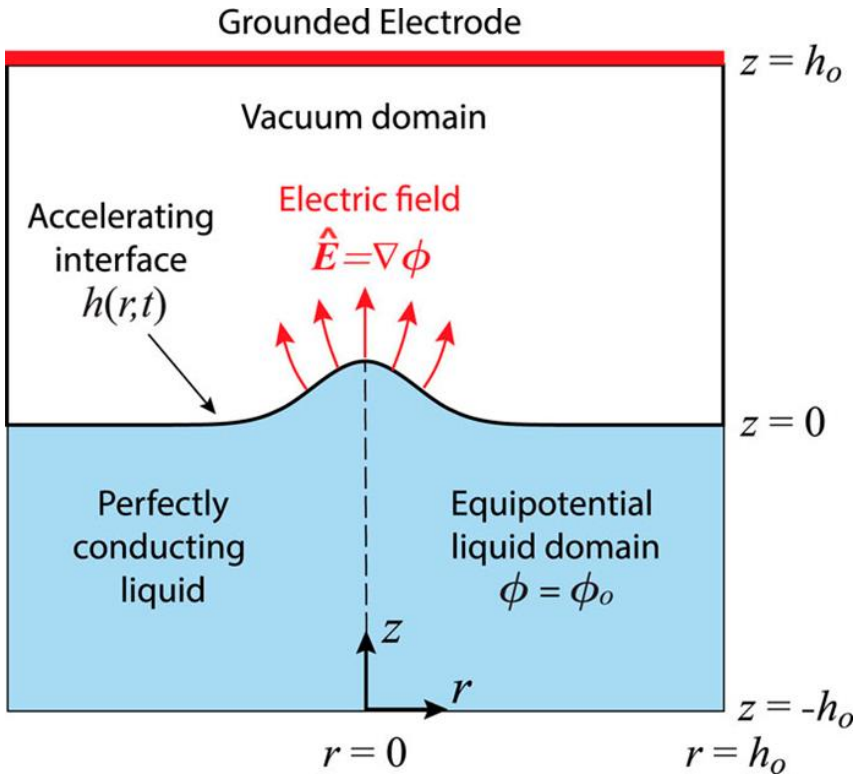
IFM Nano Thruster



Accion Systems: Emitter Array

Literature on dynamic cones

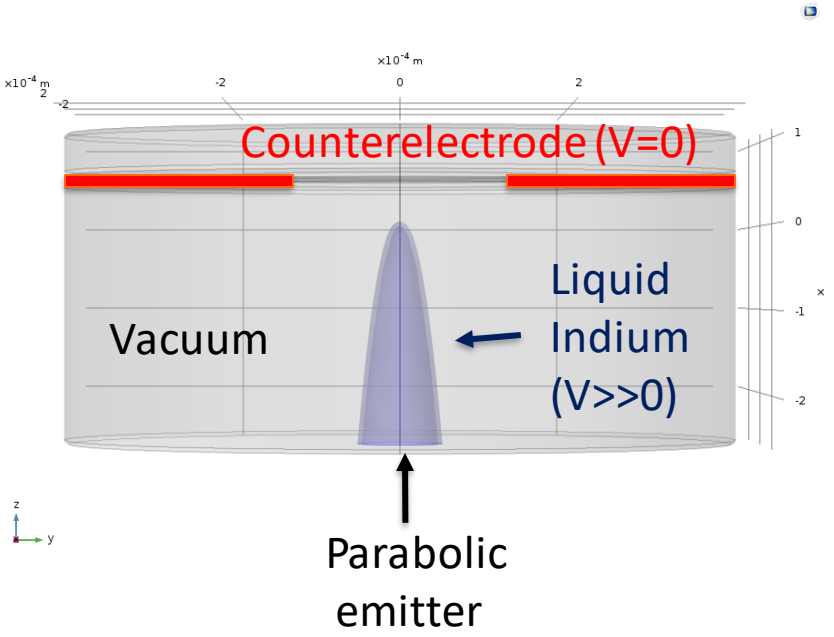
- In the literature, dynamic cones have been studied both analytically and computationally
- Studies of simplified, flat systems have shown that the cusp sharpens extremely rapidly, in self-similar fashion



T. G. Albertson and S. M. Troian, Phys. Fluids, **2019**

Influence of curvature

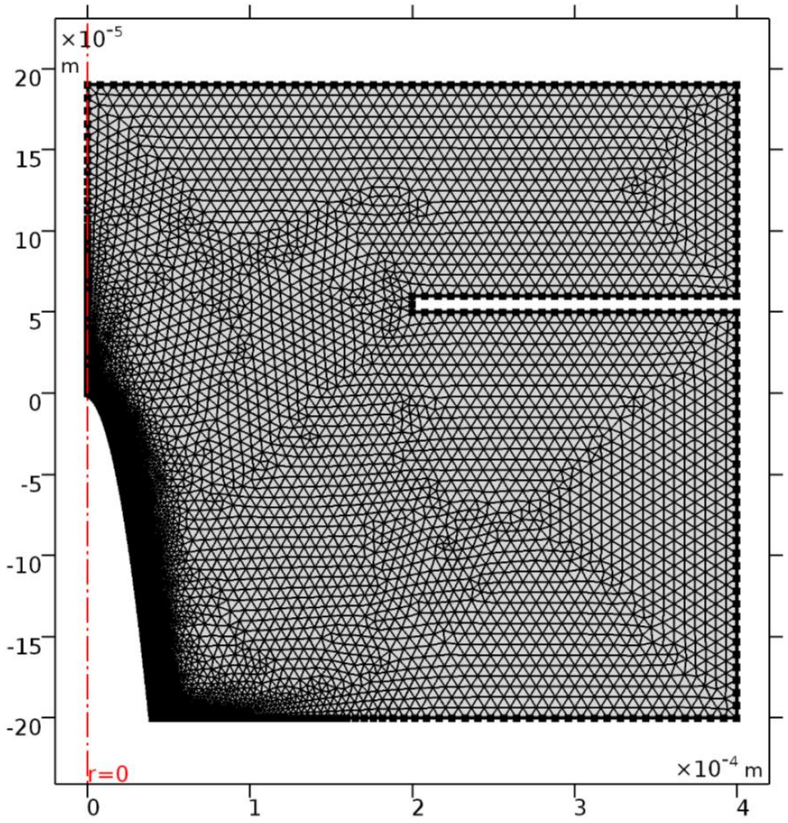
- Real devices have a curved emitter
- Sharper emitters have larger curvature
- Curvature enhances the electric field and destabilizes the liquid
- We study a parabolic emitter supporting a film of liquid indium



Representative geometry from our computational studies

Computational Methods

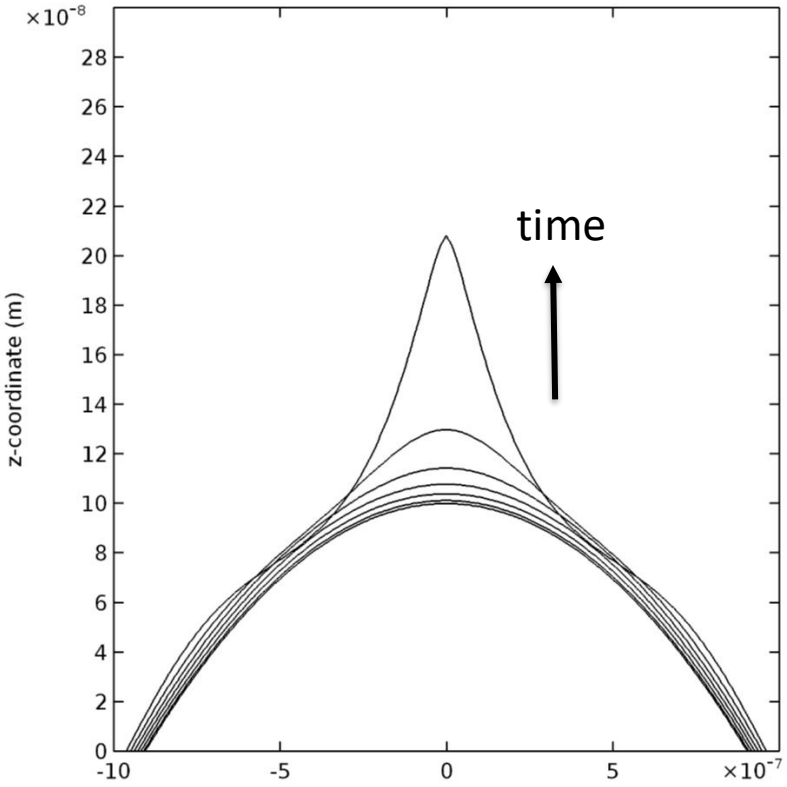
- The commercial solver, COMSOL Multiphysics, was used to solve the Navier-Stokes equations (liquid) and Laplace's equation (electrostatics) using the Finite-Element Method



A representative computational mesh from our simulations. It is denser at the liquid, where we want it to be more accurate.

Computational Results

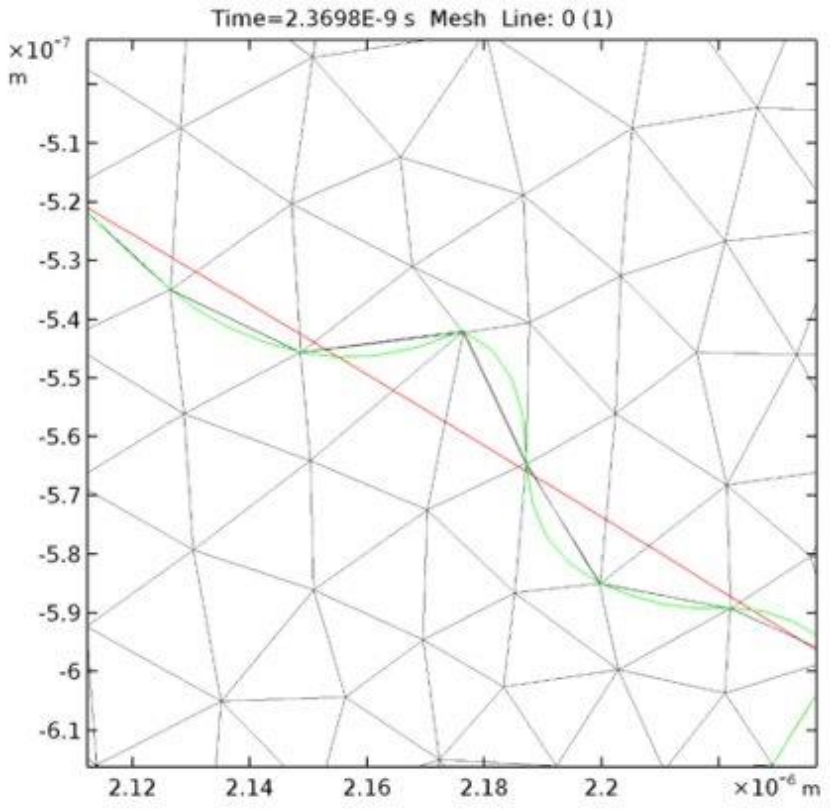
- Dynamic cones also grew self-similarly
- Simulations revealed ripples around a cone – these could also develop into cusps
- The curved emitter also modified the dispersion of fluid per turbations



A plot of the height of the fluid surface as time evolves, showing the growth of a dynamic cone

Conclusions

- It is very difficult to model the cone
- Advanced numerical methods struggled to rapidly simulate different time scales
- Further research will continue to analyze wavelets and test more parameters



A frame from a simulation that crashed, zoomed in to the highly deformed area where the numerical error occurred

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